Hierarchical Models of the Nearshore Complex System

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LONG-TERM GOALS

The long-term goal of this research is to develop and investigate abstracted models that are consistent with the constraints owing to the nonlinear, dissipative and open nature of the nearshore. Model development takes place within the framework of the nearshore as a hierarchical complex system wherein the behavior of the emerging form is related to a restricted number of variables that dominate the faster scale dynamics of the constituents.

OBJECTIVES

The specific objectives of this research project are (i) to identify the dominant variables and processes operative in the nearshore; (ii) to formulate and develop predictive, hierarchical complex systems models for nearshore processes and features, including sand bars, megaripples and surf zone currents; (iii) to relate complex systems models to measurements acquired through remote sensing; (iv) to compare complex system models to existing process-based models; and (v) to propose and design new specific field experiments capable of refuting complex systems and competing models.

APPROACH

Computer simulations, theory and field observations, experimentation and monitoring are combined to formulate, develop, test and refine models for nearshore hydrodynamics and bathymetry. The underlying

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14. ABSTRACT
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15. SUBJECT TERMS

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assumption of this research is that models for nearshore processes should reflect their nonlinear, open and dissipative nature, which selects and order variables and processes through collective self-organization (Werner, 1999; 2002). One form of variable selection in the nearshore and many other nonlinear systems is spatial localization of dynamics, owing to collective nonlinear interactions. Examples of such localization include breaking wave fronts, offshore currents localized into rips and focused bathymetric change at shorelines or sand bars. In addition, variables at different temporal scales do not interact symmetrically. This well-studied property of nonlinear, dissipative systems stems from the tendency of fast temporal scale motion to be dissipated over longer time periods. For example, the fast, but dissipative motion of a sand grain in a more sluggish offshore migrating sand bar is slaved by or follows the bar.

The traditional Reductionist Approach (fundamental physics/equations) fails for natural systems such as the nearshore because of a lack of a defensible criteria for selecting dynamical variables. The necessity that all dynamics stems from the fundamental scales and processes in Reductionism conflicts with the asymmetrical interactions between scales for nonlinear, dissipative systems, with the larger, longer scales being dominant. Universalist approaches (using the simplest system in a class of systems sharing common behaviors to model the entire class) fail because the simplifying assumptions underlying Universalist models imply an ability to treat the variability and complexity inherent in the natural environment (external to the system being studied).

A new, hierarchical modeling methodology is meant to address these criticism of Reductionism and Universality (Werner, 2002). It can be summarized with the following four steps:
(i) delineate the boundaries of the open system;
(ii) identify and temporally order dynamical variables of the system and variables in the external environment affecting system dynamics;
(iii) at each level in this temporal hierarchy, encapsulate the dynamics of faster variables into minimal rules that relate the evolution of variables at this level to each other and to the external environment;
(iv) formulate models at each level and derive testable predictions of the model;
(v) test the theoretical consistency of the modeling hierarchy by comparing predictions for a phenomenon from models at two different levels (thereby enhancing the testability of the models).

This methodology is distinguished from Reductionism and Universality by modeling phenomena at their intrinsic time scales. For example, to model sand bar motion, the variables appearing in the model describe that motion (e.g., sand bar position and height), not positions of sand grains, nor the flux of sand, nor water motions over the bar, all of which have smaller intrinsic time scales and are expected to be slaved to the motion of the bar.

WORK COMPLETED

(i) Crescentic sand bar formation was modeled with two different approaches; (ii) the stability of the longshore current has been analyzed including the effect of wave orbital velocities; (iii) analysis of megaripple occurrence and dynamics from images collected at Scripps Beach was further extended.

RESULTS

The formation and development of crescentic sand bars and the transition between different bar types are being investigated with two distinct models: a nonlinear numerical model and an abstracted model employing

emergent variables and processes. In the former model (Coco et al., 2002), most suitable for modeling formation of bathymetric features, bathymetric change is calculated using time-averaged nonlinear shallow water equations and a simplified sediment transport parameterization, and is limited to normally incident, monochromatic waves. Crescentic sand bars develop from an initially alongshore uniform barred bathymetry with a spacing roughly proportional to the width of the surf zone and a flow pattern characterized by onshore flow over the crests of the bar and strong offshore directed rips in the embayments (Figure 1).

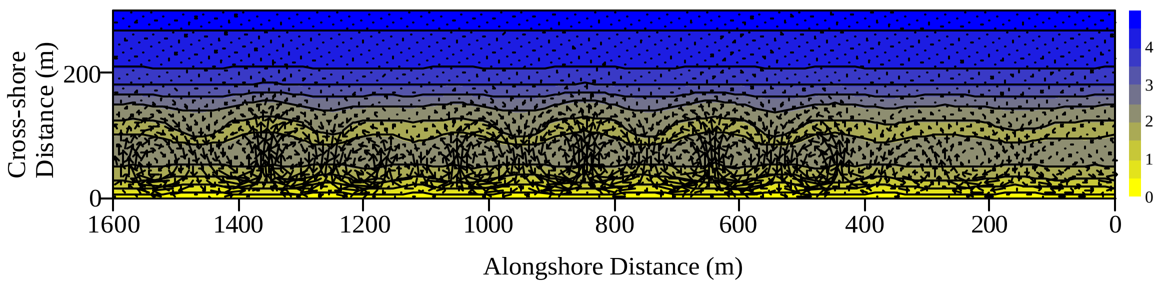

Figure 1. Development of crescentic bars
[Sand bed relative to sea level (m) after 10h of real time simulation. Initial bathymetry is characterized by an alongshore uniform bar located at 120m. Wave height is equal to 1.4m and wave period is 6s. Flow field is superimposed to the bed sea level and indicated through arrows (max arrow = 0.7m/s)]

In the latter model, most suitable for modeling evolution of existing sand bars, sand bar patterns are characterized by crestline position and height and by shoreline position. In this model, crescentic sand bars develop from a linear bar when sediment fluxes at the bar crest favor onshore migration and decrease in amplitude of the sand bar whereas if depth over the bar is large, the sand bar can migrate offshore and increase in amplitude, an instability that can lead to crescentic (Figure 2) or irregular sand bars also in the case of multiple bar systems. Equilibrium of the emerging pattern is the result of a balance between wave, current and diffusive sediment fluxes (Coco and Werner, 2002).

A linear stability analysis of equations for shear instabilities of the alongshore current including previously neglected wave orbital terms (using a time- and space-dependent Floquet approach) reveals a dependence of the predicted growth rate, wavelength and cross-shore structure on incident wave height and angle (McNamara et al., 2002). As shown in Figure 3, not only the growth rates but also the wavelength of the most unstable mode evaluated including wave orbital terms significantly differ from the analysis presented in previous studies (Bowen and Holman, 1989; Putrevu and Svendsen, 1992; Falques and Iranzo, 1994).

A surf zone sand bed imaging technique (Clarke and Werner, 2002a) was used to collect and analyze dynamical behavior of bed features. An abstracted model for saturated surf zone megaripple occurrence, based on the hypothesis that megaripples form and persist unless the bed passes through the swash zone (Figure 4) or flow conditions change too rapidly, correctly predicts the bed state (presence or absence of megaripples) for 74% of measurements over one year at Scripps Beach using independently estimated model parameters. Allowing model parameters to vary increases agreement between measurements and model predictions to a maximum of 82%. Neither bed state nor bed state transition are correlated with offshore wave conditions (Clarke and Werner, 2002b). A crest tracing algorithm (Clarke et al., 2002) enabled quantitative

measurements of megaripple crestline orientation and migration direction from processed video images (Figure 5) with which predictions from two models for bedform orientation were tested. The two models predict either steady state (Rubin and Hunter, 1987) or time-varying (Werner and Kocurek, 1997) crest orientation in response to a set of flow/transport conditions. Both models are refuted by the measurements, possibly because of the effect of strong secondary flows on orientation.

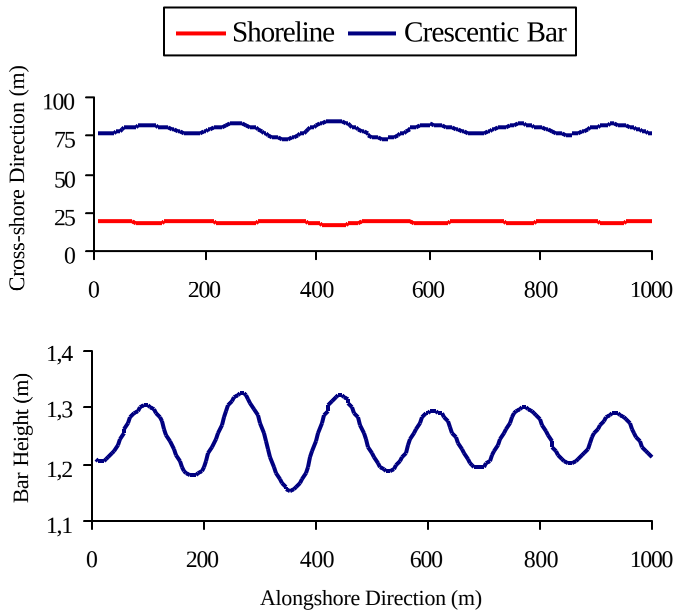

Figure 2. Development of crescentic bars
[Top panel shows the position of the equilibrium configuration of a crescentic bar system and the corresponding shoreline pattern. Bottom panel shows the variation in bar height]

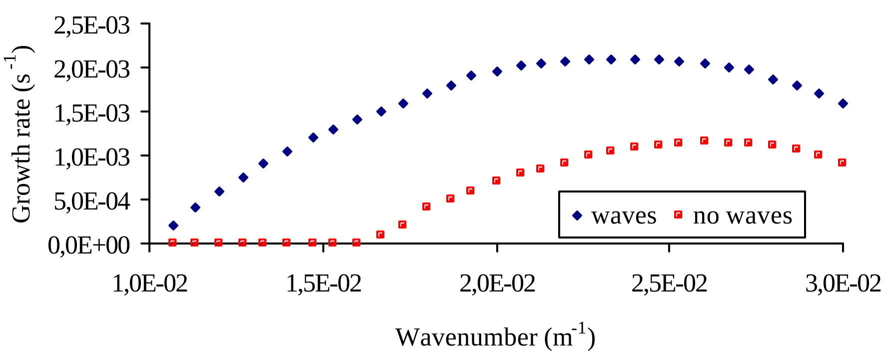

Figure 3. Growth rate as a function of alongshore wavenumber
[Growth rates are larger if wave orbital terms are included in the analysis and the most unstable mode is characterized by a shorter wavenumber]

IMPACT/APPLICATIONS

The development, implementation and testing of hierarchical complex system models for nearshore processes permit an assessment of the hierarchical methodology versus Reductionist and Universalist approaches for modeling the nearshore and for modeling other complicated natural systems.

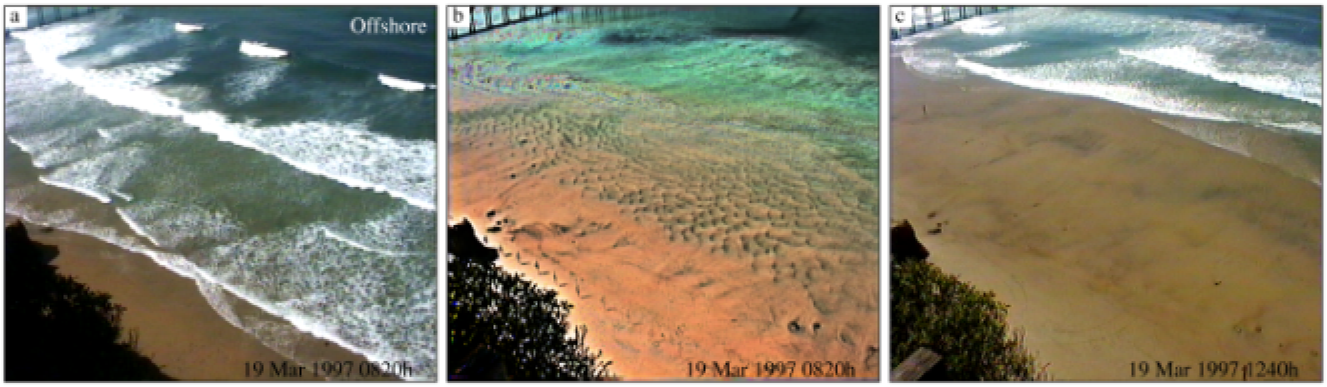

Figure 4. Destruction of megripples as they pass through the surf zone at Scripps Beach. [(a) Falling tide (single image); (b) subaqueous bedforms (processed image); (c) low tide (single image), 4.3h after panel a]

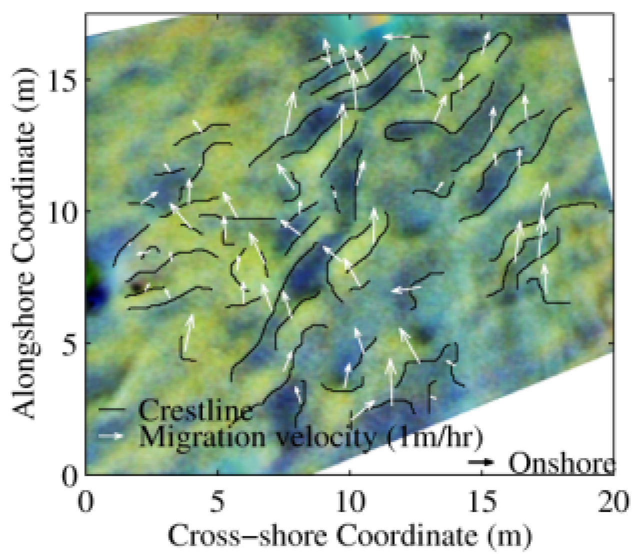

Figure 5. Creastline-mean migration velocity [Estimated crestlines positions for a processed image and corresponding migration velocities obtained from the lag giving the maximum cross-correlation of images separated by 30min.]

RELATED PROJECTS

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